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Balance function following cochlear implantation

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BALANCE FUNCTION FOLLOWING COCHLEAR IMPLANTATION

by

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***Abstract:** Imbalance is a risk of cochlear implantation. This is particularly important in patients receiving bilateral implants, who are often children. 25 adult and pediatric patients undergoing cochlear implantation were tested pre-operatively and post-operatively using tests of balance function. Results showed moderate losses in some test paradigms following implantation in the patient group as a whole. While changes in balance function due to cochlear implantation are not uncommon, their practical effect on function may be minor.*

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TABLE OF CONTENTS

LISTS OF TABLES AND FIGURES

INTRODUCTION

A cochlear implant is an electronic device that is surgically implanted into a person's inner ear or cochlea. Sound is received by an external microphone worn on the ear and then sent through a speech processor to the electrode array inside the cochlea. The sound is then sent via electrical impulses to the auditory nerve where it then travels up the auditory pathway to the brain. The cochlea is intimately linked to the vestibular system, which provides input regarding movement and equilibrium. This system has two components; the semicircular canals which indicate rotational movements and the otolith organs which indicate linear accelerations. Together with vision and the somatosensory system, the vestibular system controls a person's posture in space. The vestibular system is at risk during cochlear implantation because it is housed in the labyrinth of the inner ear and is connected to the cochlea. Since these two organs share the same fluid, changes in the cochlea could cause changes in the semicircular canals and the otolith organs of the vestibular system.

Patients sometimes report imbalance or dizziness following cochlear implant surgery. The vestibular system could be disturbed during surgery or with the electrical stimulation of the electrode. It is clinically important to estimate the risk of vestibular loss so the patient can be made fully aware of these risks when considering cochlear implantation. Research studies that have examined the vestibular function following cochlear implantation focus mostly on unilateral implants in adults and offer a wide range of conclusions. There are areas that still need to be addressed such as the effects from bilateral implantation, the effects on the pediatric population, and the effects on balance function in daily life. It is anticipated that the results of this proposed study will provide new information concerning balance function to patients considering unilateral or bilateral implantation.

Studies that have examined the effects of unilateral cochlear implantation on the vestibular system have used both subjective and objective clinical measures. Studies that have examined patients' subjective reports of imbalance post-operatively have shown a wide range of results.

Subjective Data

Buchman et al. utilized the Dizziness Handicap Inventory (DHI), a questionnaire given to patients about self-perceived balance function and found no significant change when comparing patients' scores pre- and post-operatively at 1-month, 4-months, 1-year, and 2-year periods (Buchman et al. 2004). This contrasts with a study by Steenerson et al. which interviewed patients following implantation and found 74% of patients (35/47) reported new symptoms of vertigo or imbalance (Steenerson et al. 2001). More recently, Enticott et al., used the DHI and the Activity Balance Confidence questionnaires and found that only 32% (47/146) of the patients reported significant vestibular disturbances following the surgery (Enticott et al. 2006). Similarly, Fina et al. used a symptom assessment and found that 39% (29/75) of patients reported dizziness (Fina et al. 2003). Kubo et al. and Ito conducted similar studies and found 49% (46/94) and 47% (26/55) percent of the patients respectively, reported dizziness after implantation (Ito and Ito 1998; Kubo et al. 2001).

Objective Data: Computerized Dynamic Posturography (CDP)

More objective clinical tests have been used to assess changes in vestibular function following cochlear implants and have also shown various results. Steenerson et al. measured postural stability pre-operatively and post-operatively with computerized dynamic posturography (CDP) and reported 68% (32/47) of patients to have abnormal test results following a cochlear implantation (Steenerson et al. 2001). Contrary to this study, Buchman et al. also utilized CDP in patients before and after implantation and reported improvements overall at the 1-month, 4 months, 1-year, and 2-year intervals with both the device "on" and "off" (Buchman et al. 2004).

Objective Data: Bithermal Caloric Stimulation

Ito assessed the vestibular function objectively, using bithermal caloric stimulation pre- and post-operatively and showed a functional deterioration in 38% (9/24) of the patients (Ito and Ito 1998). Ribari et al. also used bithermal caloric stimulation and found that 71% (35/49) of patients remained unchanged or showed a significant improvement in comparison to their pre-operative test results (Ribari et al. 1999). More recently, Buchman et al., using bithermal caloric stimulation, found no significant changes in either ear for the group of 47 patients (Buchman et al. 2004). Buchman confirmed these results with rotational chair testing using sinusoidal harmonic accelerations (SHA) which also assesses the function of the vestibule-ocular reflex (VOR) and found no significant changes in phase, gain, or symmetry values overall.

Objective Data: Vestibular Evoked Myogenic Potentials (VEMP)

Most recently Basta et al. used vestibular evoked myogenic potentials (VEMPs) to examine the function of the saccula following cochlear implantation. 16 patients showed normal VEMP results pre-operatively via bone conduction, however after implantation, 62% (10/16) of the patients showed a complete loss of VEMP results on the implanted side. 5 of these patients reported persistent dizziness using the DHI score greater than 40 as an objective measure (Basta et al. 2008).

The Effects of Bilateral Cochlear Implantation

Bilateral implantation has become more common as studies have revealed marked improvements in speech perception and sound localization compared to unilateral implantation (Tyler et al. 2003; Laszig et al. 2004; Schleich et al. 2004; Das et al. 2005; Verschuur et al. 2005;

Wolfe et al. 2007). Few studies have looked at the effects of vestibular function following bilateral implantation. The increased risk of clinically significant vestibular deficits may be higher in patients with bilateral cochlear implants because it is thought that those with unilateral vestibular dysfunction are better able to compensate by relying on the unaffected side.

The effects of bilateral cochlear implantation on vestibular function were investigated in an unpublished study conducted by Buchman et al. (Buchman 2005). The study tested 15 patients before and after receiving bilateral cochlear implants using the DHI and Electronystagmography. Results based on the patient's self-perceived handicap from dizziness showed 4 patients with substantial improvements, 8 patients with no significant change, and 3 patients with worsening dizziness following implantation. The electronystagmography results showed no significant changes in the vestibulo-ocular reflex (VOR) response overall. While, this study reveals no significant changes in the results of one clinical test and only a small percentage of change in patient perception, further studies are needed in this patient population before a confident conclusion can be drawn.

The Effects of Cochlear Implantation on the Pediatric Vestibular System

Research has shown that children with a profound hearing loss show significant improvements in speech and language acquisition when implanted at an early age compard to the use of conventional amplification (Osberger et al. 1993; Waltzman and Roland 2005; Nicholas and Geers 2006; Dettman et al. 2007). This has resulted in children receiving cochlear implants at much younger ages, including below age 1 year (Waltzman and Roland 2005; Dettman et al. 2007; Wolfe et al. 2007). As children are being implanted well before they can stand or walk it is important to determine if there is a higher risk of vestibular dysfunction in the pediatric population. Buchman found that of the 22 children ages 2-16 years that were tested with bithermal caloric irrigations; nearly 70% had either absent or low intensity responses pre-operatively in the ear being implanted in comparison to the 25-30% of adults who showed absent or low intensity responses (Buchman et al. 2004). Buchman concluded that children were at less risk for vestibular effects from cochlear implants than adult patients. Jin et al. examined the saccular function of children with cochlear implants using vestibular-evoked myogenic potentials (VEMPs) and found 6 of the 12 children to have normal VEMPs pre-operatively (Jin et al. 2006). Post-operatively, 1 child showed a decrease in the VEMP amplitude and 11 showed no VEMP response with the device off, while 3 of the 11 showed a VEMP response with the device on. Further studies examining the preliminary vestibular function of children with severe to profound hearing loss would assist in determining the risks to the vestibular system in children undergoing implantation. Research also needs to examine the initial and long-term effects of implantation on the functional balance of young children.

A recent study by Cushing et al. looked at the incidence of static and dynamic balance dysfunction in a group of children with profound sensorineural hearing loss and who had a cochlear implant. The study used the Bruininks-Oseretsky Test of Motor Proficiency 2 (BOT2), balance subset and found significant differences in the balance function of children with sensorineural hearing loss who had cochlear implantation in comparison to age-matched controls. This study also found that these children performed significantly on the balance-related tasks with the implant turned on (Cushing et al. 2008).

Similarly, Suarez et al. used the Postural Control test to assess the balance of deaf and normal hearing children and found children with normal hearing performed significantly better than those with sensorineural hearing loss. The results suggested that, in general, deaf children relied on visual and somatosensory information to maintain balance and activation of the unilateral cochlear implant has no effect on balance control (Suarez et al. 2007).

Although these studies have taken great steps in comparing the balance of children with implants to normal hearing children, longitudinal changes in balance ability before and after implantation in young children have not been assessed. One aspect that these recent studies have begun to embrace is the use of functional balance measures. Current clinical tests of vestibular function used to evaluated patients with cochlear implants in the studies above have several disadvantages. These tests may not accurately assess the functional difficulties patients face from dizziness (Robertson and Ireland 1995; Jacobson and Calder 2000; Perez et al. 2003; Loughran et al. 2006). Since the matter of functional performance is the primary concern of patients in regards to vestibular function, studies are needed that utilize tests that assess functional balance. One option for alternative tests are those used by Physical Therapists. These assessments may be more practical measures of a patient's actual disability and risk of falling to the standard vestibular laboratory tests. These functional tests of balance were originally developed to determine the risk of falls in the elderly but are also currently used for patients with vestibular dysfunction to measure progress during therapy. These assessments include standard balance tests such as the Timed Up and Go (TUG), The Dynamic Gait Index (DGI), and the Berg Balance Scale (BBS). Many physicians also use static balance tests such as the classic Romberg test, the tandem Romberg, the single-leg stance, and the parallel stance on foam, each with and without visual information to assess patients who complain of dizziness or imbalance. These tests assess the ability to maintain a certain position in space with altered somatosensory and visual input and may be more a more sensitive measure of vestibular dysfunction. These assessments may serve as a good alternative when vestibular test equipment is not available or when testing children who may be opposed to clinical tests.

METHODS

This study was a prospective study designed to assess the effect of unilateral or bilateral cochlear implantation on the functional balance performance and perception of dizziness in both children and adults.

The institutional review board at Washington University approved this study. Before enrollment, all subjects were informed regarding their participation in this study after which written and verbal informed consent was obtained.

Subjects

The subjects were cochlear implant candidates ages 3 years and older that were scheduled to undergo a unilateral or bilateral cochlear implantation at Washington University School of Medicine in St. Louis between June 2007 and April 2008. These subjects were recruited by the surgical team at Washington University Medical Center and the team of audiologists at Washington University Medical Center and St. Louis Children's Hospital. Consent was obtained by the research team before the first assessment took place. All subjects were given the opportunity to participate in the study. Subjects were only excluded if they were unable to understand or follow the instructions/demonstrations or if they were unable to complete an informed consent. The surgery was performed by one of five surgeons at the two facilities. A standard surgical technique used for all subjects consisted of an anteriorinferior cochleostomy and a soft insertion technique.

Procedures

The subjects underwent a battery of balance measures including the Berg Balance Scale (BBS), The Dynamic Gait Index (DGI), the Timed up and Go (TUG), and four static balance tasks which were performed with the eyes open (EO) and with the eyes closed (EC). This battery of tests was given to each subject prior to the cochlear implant surgery and was repeated three to five weeks following surgery using the same battery of tests given in the same order to ensure there was not bias due to testing fatique. During the post-implantation testing, a questionnaire was given to subjects above the age of six years assessing specific details regarding the onset, frequency, severity, and duration of any subjective dizziness that the subject may have experienced following the surgery. The Dizziness Handicap Inventory (DHI) was originally completed by each subject old enough to make subjective judgments to document any change in dizziness before and after. This questionnaire is a clinically validated instrument composed of 25 questions developed to measure a person's self-assessment of the effect that disequilibrium has on his or her life (Jacobson and Newman 1990). Because most of the subjects did not have dizziness before the surgery; the authors chose to remove this questionnaire from the protocol due to its irrelevance and length. The separate post-operative questionnaire designed by the authors had more specific questions pertinent to the study and therefore remained in the protocol.

The Berg Balance Scale

The Berg Balance Scale (BBS) was originally developed by Berg et al. to assess balance in older adults (Berg et al. 1992). This test has been used as a valuable balance assessment for subjects with vestibular disorders and although it does not measure gait, it has been well documented to be reliable and valid for subjects with vestibular dysfunction. This test is considered a "gold standard" when assessing balance and postural control clinically (Berg et al.

1992; Harada et al. 1995; Shumway-Cook and Woollacott 1995; Stevenson and Garland 1996; Whitney et al. 2003). The BBS asks the patient to perform 14 different tasks (Figure 1). Each task was scored based on the published four-point ordinal scale from 0 to 4, with 0 indicating that the subject was unable to perform the task or needed a moderate amount of assistance and 4 indicating that the subject met the task's criteria. The maximum score that can be achieved is 56. Although there are no reports of what is considered a significant change in the BBS, when used with elderly patients a score of 0 to 20 indicates a high risk for falling, 21 to 40 indicates a medium risk, and 41 to 56 indicates a low risk (Berg et al., 1992). In this study, patients were given the instructions verbally; however, demonstrations of the tasks were performed, if needed.

Figure 1: Tasks included in the Berg Balance Scale.

The Berg Balance Scale Tasks

1. Sitting unsupported
2. Change of position: sitting to standing
3. Change of position" standing to sitting
4. Transfers
5. Standing unsupported
6. Standing with eyes closed
7. Standing with feet together
8. Tandem standing
9. Standing on one leg
10. Turning trunk (feet fixed)
11. Retrieving objects from floor
12. Turning 360 degrees
13. Stool stepping
14. Reaching forward while standing

The Pediatric Berg Balance Scale (PBBS) was developed for patients under the age of 10 years. The PBBS has been validated in children for ages 5 years and above (Franjoine et al. 2003). The test modifications include reordering tasks, reducing time standards for maintenance of static postures, and clarifying the directions, all of which were used in this study's protocol when assessing children under the age of 10 years.

The Dynamic Gait Index

The Dynamic Gait Index (DGI) was developed to evaluate and document a patient's ability to modify gait in response to various tasks and predict the likelihood of falls in older adults (Shumway-Cook and Woollacott 1995). The subject is asked to perform 8 different tasks that assess the ability to walk under various demands (Figure 2). The test is graded on a 4-point scale, with 0 indicating poor performance and 3 indicating normal performance. The maximum score that can be achieved is 24. The DGI has been reported to be reliable (ICC = 0.86; kappa = 0.64) in persons with peripheral vestibular hypofunction (Wrisley et al. 2003). Scores less than or equal to 19 on the DGI are related to fall risk in older people and persons with vestibular dysfunction (Whitney et al. 2000; Hall et al. 2004). In a study by Hall et al., a change in 3 points was considered significant for patients with vestibular hypofunction (Hall et al. 2004). The DGI is thought to assess different aspects of balance and be more sensitive in testing patients with vestibular dysfunction than the BBS (Whitney et al. 2003).

Figure 2: Tasks included in the Dynamic Gait Index.

Dynamic Gait Index Tasks

1.Gait
2.Change in gait speed
3.Gait with horizontal head turns
4.Gait with vertical head turns
5.Gait and pivot turn
6.Stepping over obstacle
7.Stepping around obstacles

The DGI has yet to be studied in children, thus there is currently no normative data or test retest reliability information for the pediatric population. In this study, the instructions for the DGI were modified for younger children by using demonstrations in addition to verbal instructions.

Timed up and Go

The Timed up and Go (TUG) requires the subject to rise from a seat, walk 3 meters then turn around, return to the same seat and sit down (Podsiadlo and Richardson 1991). The score is the time in seconds from the instruction "Go" to the moment the person has sat back down. The TUG has been shown to be reliable and valid in assessing functional mobility and determining clinical change over time in patients with vestibular dysfunction (Podsiadlo and Richardson 1991; Whitney et al. 2004; Brown et al. 2006; Meretta et al. 2006). Each subject sat in a chair which was placed 3 meters from the wall. The subject was instructed that when he or she was told "Go" he or she was to rise from the chair, walk over to the wall, touch the wall, and walk back to the chair and sit back down. The timer was started when the observer said "Go." Although there are no reports of what exact value is considered a significant change in the TUG, studies have found that patients with scores greater than 11.1 seconds are at a greater risk of falling (Gill-Body et al. 2000).

The TUG was modified for children as young as 3 years and showed good test-retest reliability (Williams et al. 2005). These modifications suggested by Williams et al. were used in this study. They include asking the child to touch a target on a wall, demonstrating the test if needed, repeating the instructions during the test, and using a special seat that allowed the child's knee angle to be 90 degrees. The child was also allowed to behave spontaneously, with no specific instructions to guarantee the most natural performance possible. For the pediatric subjects, the timer was started as soon as the child left the seat, rather than on the instruction "Go," and was stopped as the child's sat back down in order to ensure that the scores measured movement only.

Timed Static Balance Tests

Timed static balance tests have been used to assess balance in patients with vestibular dysfunction (Herdman 2000; Goebel *Ten-minute examination* 2001; Goebel *Practical examination* 2001; Hansson et al. 2004; Vereeck et al. 2007). Timed static balance tests including the Romberg test, the tandem Romberg, the single-leg stance, and the parallel stance on foam, each with eyes open (EO) and eyes closed (EC) were used to assess the ability to maintain a particular position in space while altering the somatosensory and visual input (Figure 1). For each test the timer began after the subject was in the correct stance and the eyes were closed or when the subject assumed the position and indicated that he or she was ready to begin. The subjects were told how to stand but no particular rules were given regarding the placement of their arms, knee position, or visual fixation. An *Airex* Balance Pad foam pad measuring 19.5 by 16 inches and 2.5 inches thick was used in the parallel stance on foam test. The dominate foot was determined for the tandem Romberg and the single stance tests by asking the subjects which foot they used to kick a ball. That foot was used as the back foot in the tandem Romberg test and the standing foot in the single leg stance test. The clock was stopped if one of the subject's feet moved from the supporting surface, if his or her eyes open in the EC condition, if the elevated leg touched the standing leg in the single leg stance, or if the maximum time limit of 30 seconds was reached. In order to assure valid results free of error and bias, the subject was given three trials to hold the stance as long as possible. For each of these timed assessments all three trials were recorded but only the maximum time the position was held was considered for analysis. If the subject reached the 30-second time limit on the first or second trial, he or she proceeded to the next test.

Figure 3: Timed Static Balance Tests.

Romberg Test Tandem Romberg Test Single-Leg Stance Parallel Stance on Foam

These assessments were modified for younger children. A blindfold was worn in the EC conditions to ensure vision was not being used. Laminated footprints were used to assist in demonstrating and understanding the instructions. A 10 second maximum time limit was used with the very young children to accommodate the short attention span. Each of these modifications was made on a case by case basis depending on the attention span and abilities of the child.

Recently, Vereeck et al. published normative data for many of these tests; however there is still no information regarding the test-retest reliability of these timed static balance measures and therefore normal subjects were also recruited for the study to compare results (Vereeck et al. 2008). These subjects underwent a modified battery of balance measures which only included the four static balance tasks which were performed with EO and with EC. This battery of tests was given to each subject twice, once on the initial test day and then again approximately three weeks later.

For the present study, the estimated sample size was calculated to be 64 subjects, using a two tailed test with an alpha of 0.05 and a beta equal to 0.80. This sample size was calculated using an effect size of found in a study done by Hall C.D. et al. who stated that a change in DGI score of at least 3 was significant (Hall et al. 2004). The standard deviation was not given in this study; therefore a standard deviation of 6 was estimated.

RESULTS

Subjects

25 subjects undergoing cochlear implantation were tested pre-operatively and post-operatively. These included 15 children (average age 9.2(±4.4) years) and 10 adults (average age 52 (±6.5) years), undergoing unilateral (n=12) or bilateral (n=13) implantation (Table 1).

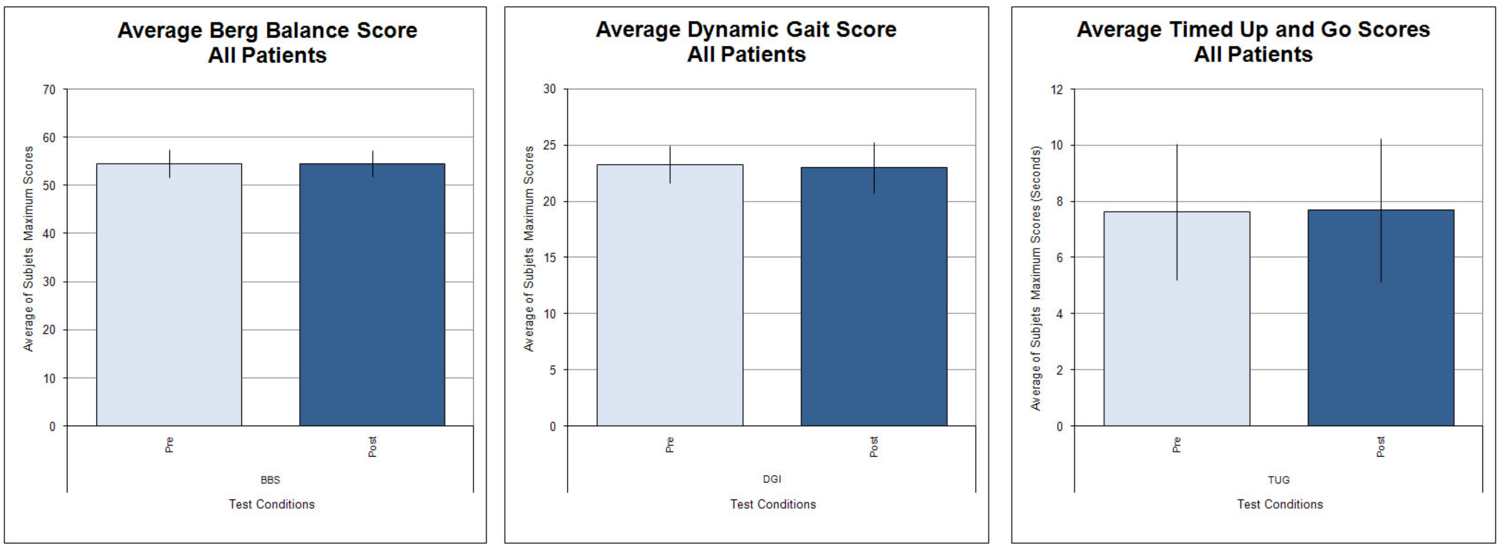
Table 1: Demographic data for 25 subjects with cochlear implants.

Subject ID	Sex	Age	Procedure Type	Ear	Processor	Etiology of Hearing Loss
1001	Male	59	Unilateral	Left	Cochlear Freedom Contour Advance	Genetic
1002	Male	15	Bilateral	Left	Cochlear Freedom Contour Advance	Unknown
1003	Female	5	Unilateral	Left	Advanced Bionics 90k Helix	Unknown
1004	Female	7	Bilateral	Left	Cochlear Freedom Contour Advance	Premature/ Respiratory Distress Requiring ventilator
1005	Male	46	Unilateral	Right	Advanced Bionics 90k Helix	Unknown
1006	Female	11	Bilateral	Right	Cochlear Freedom Contour Advance	Unknown
1007	Male	16	Unilateral	Left	Advanced Bionics 90k Helix	Unknown
1008	Female	12	Bilateral	Right	Cochlear Freedom Contour Advance	Unknown
1009	Female	4	Bilateral	Right	Cochlear Freedom Contour Advance	Unknown
1010	Female	57	Bilateral	Left	Advanced Bionics 90k Helix	Genetic
1012	Female	9	Unilateral	Left	Advanced Bionics 90k Helix	Unknown
1013	Male	8	Unilateral	Right	Advanced Bionics 90k Helix	Wardenbergs
1014	Female	71	Unilateral	Left	Cochlear Freedom Contour Advance	Unknown
1015	Female	45	Bilateral	Left	Cochlear Freedom Contour Advance	Autosomal Dominant Nonsyndromic loss
1016	Male	31	Unilateral	Left	Cochlear Freedom Contour Advance	Meningitis
1017	Female	6	Bilateral	Right	Cochlear Freedom Contour Advance	Cytomegalovirus
1018	Male	62	Unilateral	Right	Advanced Bionics 90k Helix	Unknown
1019	Male	65	Unilateral	Right	Cochlear Freedom Contour Advance	Meningitis
1021	Male	16	Bilateral	Left	Cochlear Freedom Contour Advance	Unknown
1022	Female	8	Bilateral	Right	Cochlear Freedom Contour Advance	Unknown
1024	Female	3	Simultaneous	Bilateral	Cochlear Freedom Contour Advance	Unknown
1025	Female	56	Bilateral	Right	Advanced Bionics 90k Helix	Unknown
1026	Male	14	Bilateral	Left	Advanced Bionics 90k Helix	Cytomegalovirus
1027	Female	27	Unilateral	Left	Advanced Bionics 90k Helix	Scarlet Fever and Pneumonia
1029	Male	4	Simultaneous	Bilateral	Cochlear Freedom Contour Advance	Measles High Fever

Group Data

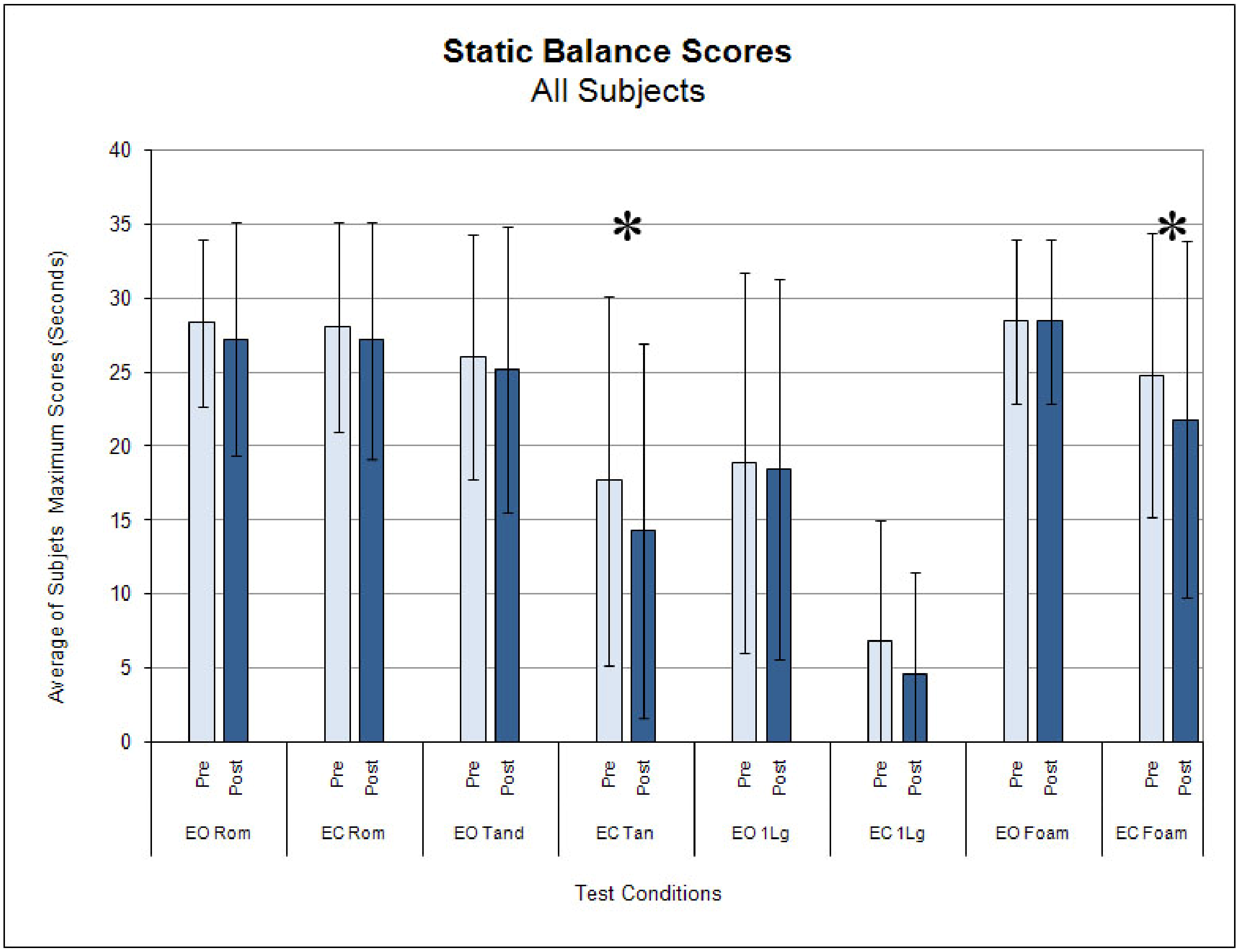
A Wilcoxon Matched-Pairs Signed-Ranks test was used to evaluate if the group scores of the BBS, DGI, TUG and the timed static tests changed significantly after implantation. No significant changes were observed in the BBS, DGI, or the TUG and little variance in scores was observed (Figure 2).

Figure 4: Average scores pre-operatively and post operatively in the BBS, DGI, and TUG observed in all cochlear implant subjects.



Of the static balance tests, significant change was seen in the Tandem Romberg EC task ($p = 0.018$) and in the parallel stance on foam EC task ($p = 0.023$). No significant change was seen in any other static balance test used (Figure 3).

Figure 5: Average scores pre-operatively and post-operatively in the timed static balance tests observed in all cochlear implant subjects. An asterisk notes change is significant.



Individual Data

Although only two static tests showed significant group change, the individual data revealed some subjects with significant change in at least one test. Because there is currently no published standard on how much change is considered clinically significant, an increase or decrease in score greater than two standard deviations from the mean change of all subjects was considered significant for the purpose of this study. The mean and standard deviation for each of the three standard balance tests and eight timed static balance tests was calculated separately to determine these significant values (Tables 2 and 3).

Table 2: Average difference in score, standard deviation and calculated improvement and diminishment thresholds for the BBS, DGI, and TUG for all cochlear implant subjects.

Dynamic Balance Tests			
	BBS	DGI	TUG
Average Score	-0.36	-0.24	-0.15
Standard Deviation	0.86	0.93	1.23
Significant Improvement	1.36	1.61	2.32
Significant Diminishment	-2.08	-2.09	-2.61

Table 3: Average difference in score, standard deviation and calculated improvement and diminishment thresholds for the timed static balance tests for all cochlear implant subjects.

Timed Static Balance Tests								
	Romberg EO	Romberg EC	Tandem Romberg EO	Tandem Romberg EC	1 Leg Stance EO	1 Leg Stance EC	Foam EO	Foam EC
Average Score	0.04	-0.04	-0.88	-4.58	-0.45	-1.60	0.00	-2.60
Standard Deviation	0.20	0.20	7.00	8.53	8.09	8.85	0.00	6.37
Significant Improvement	0.44	0.36	13.11	12.48	15.74	16.09	0.00	10.14
Significant Diminishment	-0.36	-0.44	-14.87	-21.65	-16.63	-19.29	0.00	-15.34

When analyzing the individual data using these significant thresholds, a significant diminishment in score was observed in 36% (9/25) of the subjects in at least one test. A significant improvement in score was seen in 16% (4/25) subjects, 3 of which were children. Of the 9 subjects who showed diminished scores, only 2 showed diminished scores in more than one test. Subjects who showed significant improvement did not demonstrate significant improvement in more than one test. When analyzing the individual scores of the BBS, DGI, and TUG, one child subject showed a significant diminished score in the BBS and 2 adult subjects showed significant diminished scores in the DGI. Two subjects showed significant decreases in the TUG score (one adult one child) and one adult showed a significant increase in the TUG score (Table 4).

Table 4: Amount of change in the BBS, DGI, and TUG for all cochlear implant subjects. An asterisk notes change is significant.

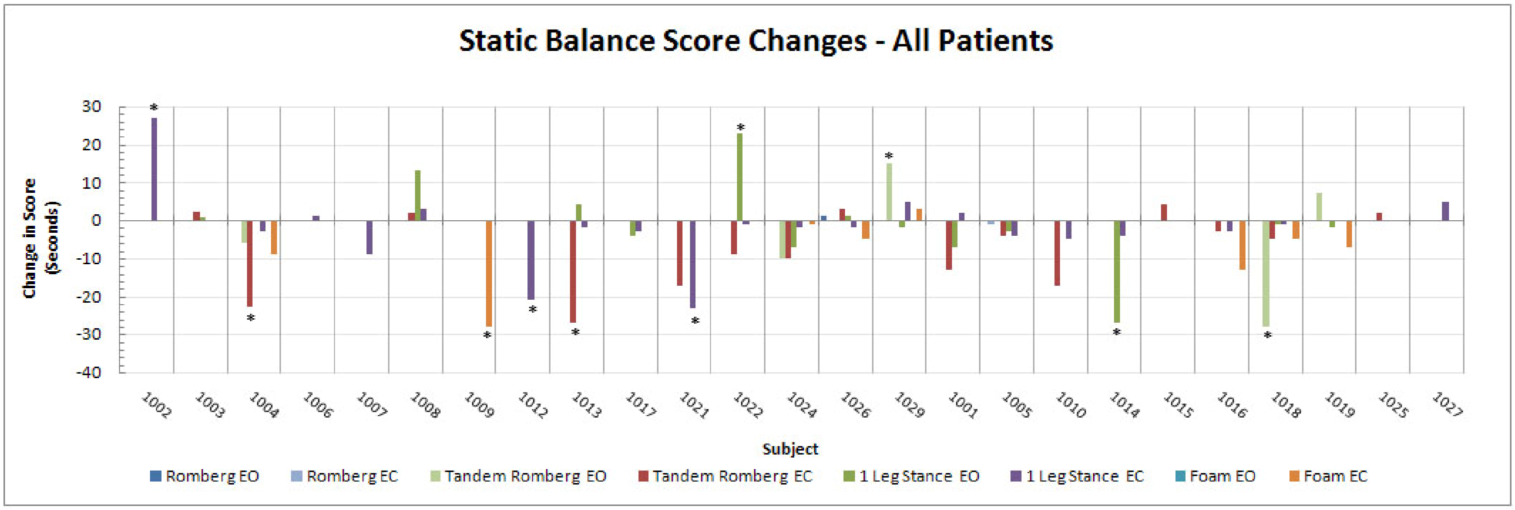
PT ID	Child/Adult	Type of Procedure	BBS	DGI	TUG
1001	Adult	Unilateral	0	0	3.04*
1002	Child	Bilateral	0	0	0.89
1003	Child	Unilateral	0	0	1.19
1004	Child	Bilateral	-3*	0	-0.38
1005	Adult	Unilateral	0	0	-1.2
1006	Child	Bilateral	0	0	1.47
1007	Child	Unilateral	0	0	0.01
1008	Child	Bilateral	0	0	-0.6
1009	Child	Bilateral	0	0	0
1010	Adult	Bilateral	0	-1	0.19
1012	Child	Unilateral	0	0	-1.26
1013	Child	Unilateral	-1	0	-0.16
1014	Adult	Unilateral	-2	-3*	-3.13*
1015	Adult	Bilateral	0	O	-0.1
1016	Adult	Unilateral	-2	0	-1.28
1017	Child	Bilateral	-1	-1	0.15
1018	Adult	Unilateral	0	0	0
1019	Adult	Unilateral	-1	-3*	-0.03
1021	Child	Bilateral	0	0	-0.27
1022	Child	Bilateral	1	1	-2.81*
1024	Child	Unilateral	0	0	0
1025	Adult	Bilateral	0	1	-0.22
1026	Child	Bilateral	0	0	0.47
1027	Adult	Unilateral	0	0	0.4
1029	Child	Bilateral	0	0	0

When analyzing the individual scores of the static balance tests, significant diminished scores were seen in 28% (7/25 - 2 adults and 5 children) and significant improvements were observed in 12% (3/25) subjects (all children). Of the significant diminishments observed, 71% (5/7) occurred in the eyes-closed tests and 29% (2/7) occurred in the eyes-open tests (Table 5 and Figure 4).

Table 5: Amount of change in the timed static balance tests observed in all cochlear implant subjects. An asterisk notes change is significant.

PT ID	Child/Adult	Type of Procedure	Romberg EO	Romberg EC	Tandem Romberg EO	Tandem Romberg EC	1 Leg Stance EO	1 Leg Stance EC	Foam EO	Foam EC
1001	Adult	Unilateral	0	0	0	-13	-7	2	0	0
1002	Child	Bilateral	0	0	0	0	0	27*	0	0
1003	Child	Unilateral	0	0	0	2.4	0.81	0	0	0
1004	Child	Bilateral	0	0	-6	-22.94*	0	-3	0	-9
1005	Adult	Unilateral	0	-1	0	-4	-3	-4	0	0
1006	Child	Bilateral	0	0	0	0	0	1	0	0
1007	Child	Unilateral	0	0	0	0	0	-9	0	0
1008	Child	Bilateral	0	0	0	2	13	3	0	0
1009	Child	Bilateral	0	0	0	0	0	0	0	-28*
1010	Adult	Bilateral	0	0	0	-17	0	-5	0	0
1012	Child	Unilateral	0	0	0	0	0	-21*	0	0
1013	Child	Unilateral	0	0	0	-27*	4	-2	0	0
1014	Adult	Unilateral	0	0	0	0	-27*	-4	0	0
1015	Adult	Bilateral	0	0	0	4	0	0	0	0
1016	Adult	Unilateral	0	0	0	-3	0	-3	0	-13
1017	Child	Bilateral	0	0	0	0	-4	-3	0	0
1018	Adult	Unilateral	0	0	-28*	-5	-1	-1	0	-5
1019	Adult	Unilateral	0	0	7	0	-2	0	0	-7
1021	Child	Bilateral	0	0	0	-17	0	-23*	0	0
1022	Child	Bilateral	0	0	0	-9	23*	-1	0	0
1024	Child	Unilateral	0	0	-10	-10	-7	-2	0	-1
1025	Adult	Bilateral	0	0	0	2	0	0	0	0
1026	Child	Bilateral	1	0	0	3	1	-2	0	-5
1027	Adult	Unilateral	0	0	0	0	0	5	0	0
1029	Child	Bilateral	0	0	15*	0	-2	5	0	3

Figure 6: Amount of change in all timed static balance tests observed in subjects with cochlear implants. An asterisk notes change is significant.



Normative Data

Normative data was collected in 13 subjects (average age 24 (±6) years) to determine if the changes observed in the static balance tests were just chance error (Table 6).

Table 6: Demographic data for 13 subjects with normal hearing.

Subject ID	Age	Sex
2001	27	Female
2002	24	Female
2003	24	Female
2004	25	Female
2005	24	Female
2006	25	Female
2007	25	Female
2008	25	Female
2009	24	Female
2010	25	Female
2011	43	Male
2012	34	Female
2013	36	Female

A significant change was observed in one subject who showed a significant improvement in the Tandem Romberg EC test. No other significant changes were seen within this control group (Table 7).

Table 7: Amount of change in the timed static balance tests observed in subjects with normal hearing. An asterisk notes change is significant.

Subject ID	Age	Romberg EO	Romberg EC	Tandem Romberg EO	Tandem Romberg EC	1 Leg Stance EO	1 Leg Stance EC	Foam EO	Foam EC
2001	27	0	0	0	0	0	-3	0	0
2002	24	0	0	0	0	0	-2	0	0
2003	24	0	0	0	17*	0	-13	0	0
2004	25	0	0	0	0	0	0	0	0
2005	24	0	0	0	0	0	0	0	0
2006	25	0	0	0	0	0	0	0	0
2007	25	0	0	0	0	0	0	0	0
2008	25	0	0	0	0	0	0	0	0
2009	24	0	0	0	0	0	0	0	0
2010	25	0	0	0	0	0	-9	0	0
2011	43	0	0	0	0	0	-2	0	0
2012	34	0	0	0	0	0	9	0	0
2013	36	0	0	0	3	0	10	0	0

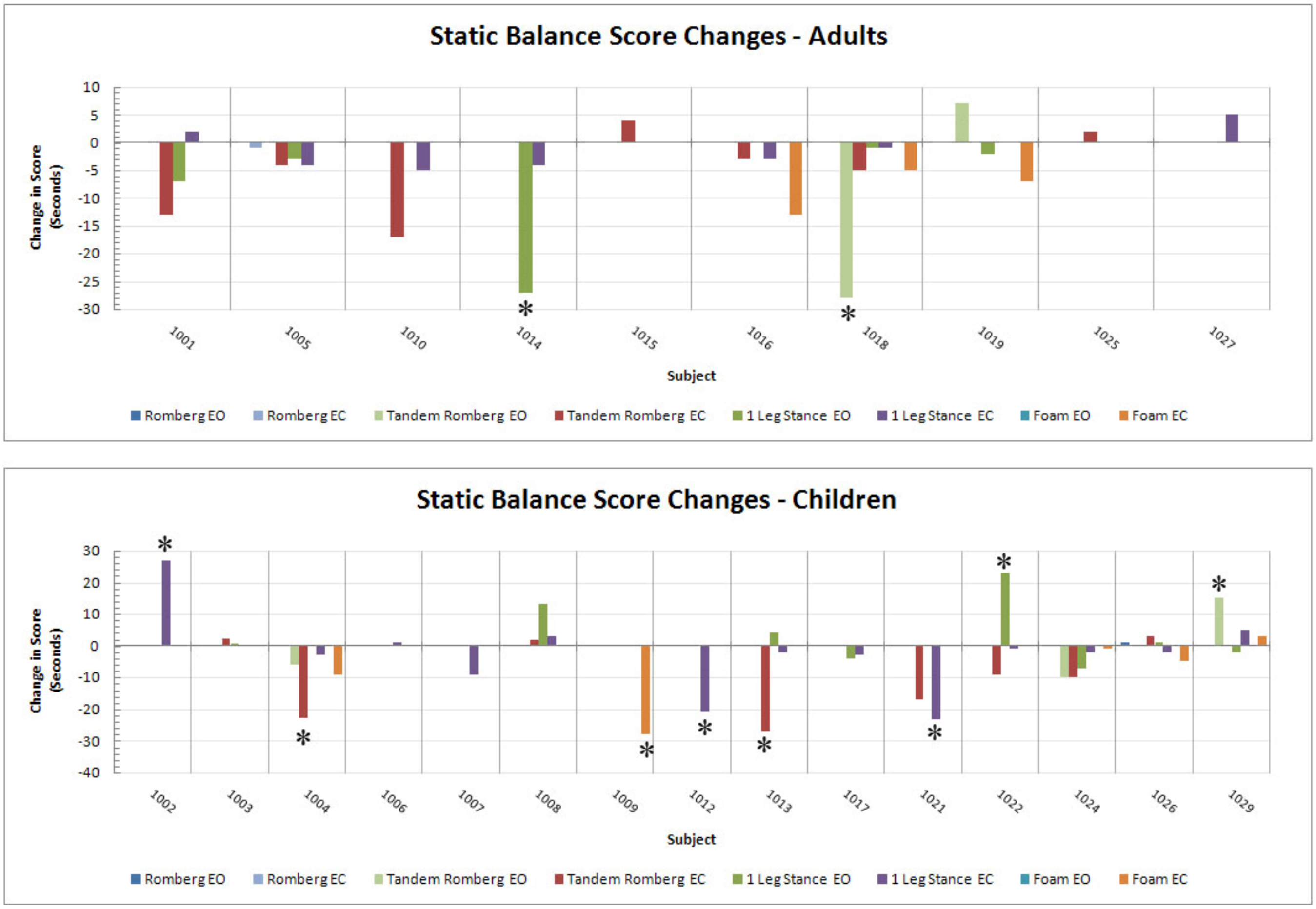
Adults and Children

Significant diminishments in scores were seen in 30% (3/10) adults and in 40% (6/15) children in at least one balance test (Table 8 and Fig. 4). Significant improvements were seen in 10% (1/10) adults and 20% (3/15) children (Table 8 and Figure 5).

Table 8: Amount of change in all balance tests observed in subjects with cochlear implants separated by age. An asterisk notes change is significant.

Subject ID	Child/Adult	Type of Procedure	Romberg EO	Romberg EC	Tandem Romberg EO	Tandem Romberg EC	1 Leg Stance EO	1 Leg Stance EC	Foam EO	Foam EC	BBS	DGI	TUG
1002	Child	Bilateral	0	0	0	0	0	27*	0	0	0	0	0.89
1003	Child	Unilateral	0	0	0	2.4	0.81	0	0	0	0	0	1.19
1004	Child	Bilateral	0	0	-6	-22.94*	0	-3	0	-9	-3*	0	-0.38
1006	Child	Bilateral	0	0	0	0	0	1	0	0	0	0	1.47
1007	Child	Unilateral	0	0	0	0	0	-9	0	0	0	0	0.01
1008	Child	Bilateral	0	0	0	2	13	3	0	0	0	0	-0.6
1009	Child	Bilateral	0	0	0	0	0	0	0	-28*	0	0	0
1012	Child	Unilateral	0	0	0	0	0	-21*	0	0	0	0	-1.26
1013	Child	Unilateral	0	0	0	-27*	4	-2	0	0	-1	0	-0.16
1017	Child	Bilateral	0	0	0	0	-4	-3	0	0	-1	-1	0.15
1021	Child	Bilateral	0	0	0	-17	0	-23*	0	0	0	0	-0.27
1022	Child	Bilateral	0	0	0	-9	23*	-1	0	0	1	1	-2.81*
1024	Child	Unilateral	0	0	-10	-10	-7	-2	0	-1	0	0	0
1026	Child	Bilateral	1	0	0	3	1	-2	0	-5	0	0	0.47
1029	Child	Bilateral	0	0	15*	0	-2	5	0	3	0	0	0
1001	Adult	Unilateral	0	0	0	-13	-7	2	0	0	0	0	3.04*
1005	Adult	Unilateral	0	-1	0	-4	-3	-4	0	0	0	0	-1.2
1010	Adult	Bilateral	0	0	0	-17	0	-5	0	0	0	-1	0.19
1014	Adult	Unilateral	0	0	0	0	-27*	-4	0	0	-2	-3*	-3.13*
1015	Adult	Bilateral	0	0	0	4	0	0	0	0	0	o	-0.1
1016	Adult	Unilateral	0	0	0	-3	0	-3	0	-13	-2	0	-1.28
1018	Adult	Unilateral	0	0	-28*	-5	-1	-1	0	-5	0	0	0
1019	Adult	Unilateral	0	0	7	0	-2	0	0	-7	-1	-3*	-0.03
1025	Adult	Bilateral	0	0	0	2	0	0	0	0	0	1	-0.22
1027	Adult	Unilateral	0	0	0	0	0	5	0	0	0	0	0.4

Figure 7: Amount of change in all timed static balance tests observed in subjects with cochlear implants separated by age. An asterisk notes change is significant.



Fisher's Exact Probability test was used to determine if there was a significant relationship between age group and the occurrence of any change or the occurrence of a specific type of change (diminishment or improvement). No significant relationships were found.

Unilateral and Bilateral Subjects

Significant diminishments in scores were seen in 31% (4/13) bilateral implantees and 42% (5/12) unilateral implantees in at least one static balance test. Significant improvements were seen in 23% (3/13) bilateral implantees and 8% (1/12) unilateral implantees (Table 9).

Table 9: Amount of change in all balance tests observed in subjects with cochlear implants separated by procedure type. An asterisk notes change is significant.

Subject ID	Child/Adult	Type of Procedure	Romberg EO	Romberg EC	Tandem Romberg EO	Tandem Romberg EC	1 Leg Stance EO	1 Leg Stance EC	Foam EO	Foam EC	BBS	DGI	TUG
1003	Child	Unilateral	0	0	0	2.4	0.81	0	0	0	0	0	1.19
1007	Child	Unilateral	0	0	0	0	0	-9	0	0	0	0	0.01
1012	Child	Unilateral	0	0	0	0	0	-21*	0	0	0	0	-1.26
1013	Child	Unilateral	0	0	0	-27*	4	-2	0	0	-1	0	-0.16
1024	Child	Unilateral	0	0	-10	-10	-7	-2	0	-1	0	0	0
1001	Adult	Unilateral	0	0	0	-13	-7	2	0	0	0	0	3.04*
1005	Adult	Unilateral	0	-1	0	-4	-3	-4	0	0	0	0	-1.2
1014	Adult	Unilateral	0	0	0	0	-27*	-4	0	0	-2	-3*	-3.13*
1016	Adult	Unilateral	0	0	0	-3	0	-3	0	-13	-2	0	-1.28
1018	Adult	Unilateral	0	0	-28*	-5	-1	-1	0	-5	0	0	0
1019	Adult	Unilateral	0	0	7	0	-2	0	0	-7	-1	-3*	-0.03
1027	Adult	Unilateral	0	0	0	0	0	5	0	0	0	0	0.4
1002	Child	Bilateral	0	0	0	0	0	27*	0	0	0	0	0.89
1004	Child	Bilateral	0	0	-6	-22.94*	0	-3	0	-9	-3*	0	-0.38
1006	Child	Bilateral	0	0	0	0	0	1	0	0	0	0	1.47
1008	Child	Bilateral	0	0	0	2	13	3	0	0	0	0	-0.6
1009	Child	Bilateral	0	0	0	0	0	0	0	-28*	0	0	0
1017	Child	Bilateral	0	0	0	0	-4	-3	0	0	-1	-1	0.15
1021	Child	Bilateral	0	0	0	-17	0	-23*	0	0	0	0	-0.27
1022	Child	Bilateral	0	0	0	-9	23*	-1	0	0	1	1	-2.81*
1026	Child	Bilateral	1	0	0	3	1	-2	0	-5	0	0	0.47
1029	Child	Bilateral	0	0	15*	0	-2	5	0	3	0	0	0
1010	Adult	Bilateral	0	0	0	-17	0	-5	0	0	0	-1	0.19
1015	Adult	Bilateral	0	0	0	4	0	0	0	0	0	o	-0.1
1025	Adult	Bilateral	0	0	0	2	0	0	0	0	0	1	-0.22

Fisher's Exact Probability test was used to determine if there was a significant relationship between the occurrence of any change or the occurrence of a specific type of change (diminishment or improvement) with the type of procedure (unilateral or bilateral). No significant relationships were found.

Subjective Data

Seventeen subjects were able understand and answer the post-operative dizziness questionnaire. Of these 17 subjects, 47% (8/17) reported post-operative dizziness (Table 10).

Table 10: Reports of subjective post-operative “dizziness.”

Subject ID	Age	Dizziness	Onset	Imbalance	Lightheaded	Vertigo	Duration
1001	59						
1002	15	X	Within 24 Hours	x			Short
1003	5						
1004	7						
1005	46						
1006	11	X	Within 24 Hours	x			Short
1007	16						
1008	12						
1009	4						
1010	57						
1012	9						
1013	8						
1014	71	X	Within 24 Hours	x		X	Short
1015	45	X	Within 24 Hours			X	Long
1016	31						
1017	6						
1018	62						
1019	65	X	After 24 Hours	x			Short
1021	16	X	After 24 Hours	x	X	X	Long
1022	8						
1024	3						
1025	56	X	After 24 Hours	x			Short
1026	14						
1027	27	X	Within 24 Hours	x			Moderate
1029	4						

Three of 7 subjects who demonstrated a significant diminishment in one of the tests of balance reported dizziness post-operatively. Fisher’s Exact Probability test was calculated to determine if significant relationship could be found between significant decreases in balance test score and subjective reports of dizziness. No significant relationship was found.

DISCUSSION

A large number of studies, using both subjective and objective tests, have examined the effects of cochlear implantation on balance. Some studies suggest a significant risk for vestibular complications and some suggest very little. This uncertainty, combined with recent changes in eligibility for implantation as well as surgical technique, suggested that further study was merited in order to best counsel subjects about possible imbalance following implantation. In addition, previous studies have relied on subjective questionnaires and conventional laboratory tests to measure vestibular function, while a patient's actual ability to function in more realistic situations may be more representative during tests of balance.

Group Data

The results of this study showed significant change in the tandem Romberg EC and parallel stance on foam with EC. These results are consistent with vestibular loss because they selectively remove vision and somatosensory leaving the subject more reliant on vestibular cues. Other tests did not show significant changes. This may be a result of sample size or reflect a relatively mild or minor effect in most patients. It may also reflect that some patients are better able to compensate for vestibular dysfunction.

Individual Data

Although group data showed a change on selected tests, analysis of individual scores showed changes in 48% (12/25) of subjects. 36% (9/25) of subjects showed diminished scores following cochlear implantation. Of the significant diminishments observed in the static balance tests, 71% (5/7) occurred in the eyes-closed tests and 29% (2/7) occurred in the eyes-open tests. This was not surprising as the eyes-closed tests are more sensitive to vestibular system function.

Of the standard balance tests, there was one significant decrease seen in the BBS, two significant decreases in the DGI, the TUG. Significant changes in these tests were determined specifically for this study, although the value specified for the DGI in this study is the same value that was used by Hall et al. to examine change with vestibular rehabilitation (Hall et al. 2004). These significant decreases in these two tests were not found in the same subjects, however, it has been thought that these two tests measure differing components and often are not found to correlate perfectly (Whitney et al. 2003). There are no current data regarding the amount of change deemed significant for the BBS.

The published values used to determine risk for falling from the DGI score and the BBS are equal to or lower than 19 for the DGI and 40 for the BBS. No subject had a score below 40 for the BBS and two subjects were found to have DGI scores lower than 19. Of these two subjects, one was a very young child whose score did not change pre- and post-operatively. The other subject was the second oldest subject included in the study (subject 1019). This subject's scores did change significantly post-implantation, and could therefore indicate a loss in function. This was the only subject who showed both a significant diminishment and a high risk falling based on the published criteria.

Based on the threshold for significant change determined for the TUG, two subjects were found to change significantly pre-to post-operatively. There is currently no literature regarding the amount of change that is considered clinically significant with the TUG. However, Whitney et al. found that scores greater than 11.1 seconds were correlated with a high risk for falling in people with vestibular disorders (Whitney et al. 2004). Only one subject in this study was found to have a TUG score greater than 11.1. This was again the subject 1019, however, unlike the DGI score, the TUG score did not change significantly following implantation. These thresholds for risk published for the BBS, DGI, and the TUG may be sufficient for determining patients at risk for falling, but the amount of change that is considered significant still needs to be determined. The two subjects that showed a significant diminished score in the TUG were not found to have scores higher than the 11.1 risk criteria.

Bilateral and Unilateral Subjects

A significant decrease was seen in 4/13 bilateral implantees and 5/12 unilateral implantees in at least one balance test. No significant association between the occurrence change and the two types of procedures types was found. Therefore changes do not seem to be found more in those implanted unilaterally than those implanted bilaterally. It was thought that if implantation caused damage to the vestibular system, those with bilateral damage would show more diminished scores post-operatively. Therefore the authors were surprised to find that unilateral subjects did not fare significantly better than the bilateral subjects. This may indicate that bilateral cochlear implantation has a low risk of damaging the vestibular system bilaterally and therefore deterioration in balance scores would not be observed. It is also possible that subjects with incomplete losses from the first implant are already compensating for vestibular dysfunction associated with the hearing loss and therefore disruption to the vestibular system would not change balance performance significantly.

Adults and Children

A significant decrease was seen in 3/10 adults and in 6/15 children in at least one test of balance when examining the changes that occurred in both the dynamic and static balance tests. No association was found between age group and change in score, therefore, the chance of loss was not found to be more prevalent in either children or adults. Enticott et al. found that those 70 years and older had a significantly greater incidence of permanent vestibular symptoms after implantation (Enticott et al. 2006). Geriatric patients may represent a separate group that was not well represented in the sample as the oldest subject included was 71 years old. Interestingly, the oldest patient was the only patient to show diminished scores on 3 of the tests. This individual result highlights the need for, further research of functional balance in the geriatric population before and after.

3/4 patients demonstrating significant improvements were children. The authors believe that it is unlikely that these improvements represent a true change in vestibular function as they were only seen in a small number of subjects. These rare cases of improved scores differ from other studies which found a significant number of improvements in postural stability after the cochlear implant was activated (Eisenberg et al. 1982; Buchman et al. 2004; Cushing et al. 2008).

A number of measures were taken to improve the reliability of test results in very young children. The selected tasks were simple for a child above the age of three to perform. A parent or guardian was always present during the testing to ensure the child was comfortable. If the child was unable to reach the maximum score of a static balance test initially, three trials were given to ensure the child was given plenty of opportunity to achieve the most reliable score. Since many of the children were younger in age, factors such as attention or comfort with the test procedures may have impacted their score.

Pre-operative Balance Function

Cochlear implantees have been found to have lower than normal functional balance scores both pre- and post-operatively (Vereeck et al. 2008). This may point to the speculations that those undergoing cochlear implantation already have compromised vestibular systems associated with the hearing loss. Previous findings have suggested that patients with poorer pre-operative function as determined by laboratory tests would lead to poorer subjective results post-operatively demonstrated by measures such as the DHI (Fina et al. 2003). Our results however do not suggest that poor pre-operative function increases the chances of a decrease in balance function. Our findings suggest that people who have some problem pre-operatively have the same chance of losing function. Still, loss of function may be more important in people who are already struggling with balance difficulties.

Trends in Changes

It is the vestibular system along with vision and somatosensory system, which is the sensations of muscle movement and joint position in the hips, legs, ankles and feet, that all work together to keep a person upright and oriented in space. When vision is removed, more strain is placed on the two other systems. When subjects are in the tandem Romberg position, even more strain is placed on the vision and vestibular system because the subjects' base has narrowed due to the positioning of their feet. In this position, the balance system must work harder to keep the body from swaying laterally as well as frontward and backward because of the narrow base and the limitation on the ankles. Those with vestibular deficits often fail this test because they are relying on their vision to compensate for the vestibular dysfunction (Goebel 2001). Similarly, the single leg stance also decreases the size of the base and removes some of the somatosensory input, placing more stress on the vision and vestibular system. The parallel stance on foam also increases the strain on the vestibular system as it decreases the somatosensory input from both feet by placing the subject on an unsteady surface. The parallel stance on foam with the EO and EC is similar to conditions 5 and 6 on Computerized Dynamic Posturography (CDP), called the "vestibular conditions." An inability to remain upright in these conditions indicates that there is a vestibular dysfunction. Therefore it can be said that the changes seen in the parallel stance on foam resulted from a change in vestibular function rather than test retest error.

There is the possibility of learning effects or test re-test error in these tests of balance function, meaning that some individuals' scores will improve with every trial or naturally fluctuate from day to day. However this is unlikely because this data would then show more improvements or the same chance of the chance of getting better as getting worse. Most changes observed were diminished scores rather than improvements. A more uniform distribution of change would have also been found rather than change in only a particular set of tests. The data show that the subjects were more likely to get worse on the “vestibular conditions,” conditions without vision. Similarly to the group data, significant decreases in the individual data were more common in the eyes-closed paradigms suggesting that losses observed were actually related to vestibular compromise and were not simply statistical sampling error. The absence of change in the control group also suggests that a learning phenomenon or test-retest error did not seem to bias the results. Thus it is unlikely that these changes are just random chance. Although the changes could be the result of variables such as attention to each test or fatigue the authors attempted to manage these variables by delivering the tests in the same order each session.

Of the 9 subjects that showed a significant diminishment in score(s), only two subjects showed diminished scores in more than one test, indicating that even after implantation, most subjects could still perform well on a wide variety of balance-related tasks. Our clinical impression of the implantees included in this study does not demonstrate any subjects with severe losses in balance function. It is thought that grave changes in balance would probably have yielded significant change across multiple tests. If catastrophic losses to balance function do occur following implantation, they may be rare as these tests of balance did not reveal any in this sample of 25 implantees. This conclusion is supported by the lack of case reports of devastating vestibular complications following cochlear implantation and signifies the safety of implantation.

Subjective Data

The subjective data obtained from the questionnaires were not found to correlate with significant changes in balance. These results are similar to Buchman’s study which showed patients with a significant self-perceived dizziness, but did not show significant dysfunction on objective tests (Buchman et al. 2004). It may be that those with self-perceived dizziness have adaptive mechanisms that allow them to compensate for their loss or that the subjective dizziness following implantation is the result of other surgical factors. Although the questionnaire tried to target the onset, duration, and particular type of dizziness the patient experienced, subjects expressed that it was difficult to differentiate and describe what they had experienced.

As mentioned, the Dizziness Handicap Inventory (DHI), a standard questionnaire of subjective dizziness, was originally completed by each subject old enough to make subjective judgments. The questionnaire was used in hopes of documenting any change in subjective dizziness following implantation, however this questionnaire was eventually eliminated from the test battery because most subjects did not complain of dizziness before the surgery and many were confused by the questionnaire because many were being asked questions about dizzy symptoms that they never experienced. In addition, the DHI is a lengthy questionnaire and most of the questions included were found to be irrelevant to the dizziness that the subjects experienced. Since the DHI did not target the information needed the authors chose to rely solely on the more specific questionnaire designed specifically for the study to assess any dizziness the subject may have experienced post-operatively.

Normative Data

Of the 13 subjects in the control group which did not undergo cochlear implantation, only one subject showed a significant improvement in score and no subjects showed significant diminished scores. This strengthens the belief that the diminished scores seen in the cochlear implanted subjects between pre- and post-operative intervals are not test-retest error but are due to factors involved in the cochlear implantation procedure. The normative data collected did not include any children; therefore this data should only be compared to the adult cochlear implant subject data.

The threshold for change used to determine significant change was based only on the average change observed in this sample. This threshold was reasonably determined, but whether it represents a clinically significant change needs to be investigated further. The method used to determine significance found that a decrease in score of 3 points or greater was considered significant for the DGI. This is in agreement with results from one study which stated that a change in DGI score of at least 3 was significant (Hall et al. 2004). A threshold of significance for the Romberg test with EO and EC was calculated to be less than one second. Although two patients showed a change in the Romberg test of one second, these changes were not deemed significant as such a short period could be a highly influenced by small timer errors. Ideally, the threshold for significant change should be determined from a sample of normal hearing people with no vestibular issues. Although normative data were collected for this study and showed little change in scores, a larger and more representative sample is needed to better determine thresholds for comparative purposes.

Key Features

A key distinction between this study and previous ones is that behaviorally relevant tests examining changes in standing and walking were incorporated. The BBS and the DGI are tests designed for the elderly or low functioning subjects to determine the risk of falling and were included in this study because they are of the few standardized tests of functional balance that have been used clinically to test those with vestibular dysfunction. However, the DGI and the BBS have maximum scores which most subjects in this study achieved pre- and post-operatively. When comparing the average scores and standard deviations of the DGI and the BBS to the results obtained in a study by Whitney et al., it seems that the subjects in the present study showed a much higher average and lower standard deviations both pre- and post- operatively than found in a group of 70 patients with vestibular dysfunction (Whitney et al. 2000). These tests may have a ceiling effect for higher functioning patients like those included in this study and may not be sensitive tests in determining their balance function (Vereeck et al. 2008).

The dizziness and imbalance that patients report after cochlear implantation are often not debilitating, therefore more sensitive tests were included in the battery to try to identify small changes in balance after implantation. The TUG was included as it does not have a maximum score yet still assesses dynamic movements. There is currently no literature regarding the amount of change that is considered clinically significant with the TUG. Timed static balance tests were also included in the study as these tests of balance are often used as bedside assessments for patients experiencing dizziness, however, further research is needed to determine the correlation between amount of change in scores and vestibular loss.

Each of these tests can assess the change to balance function versus clinical status of the vestibular system which better addresses the concerns of patients considering cochlear implantation. These tasks have the advantage of being available for use in small children and are simple, quick, transportable, and inexpensive to deliver. Such testing paradigms may become standard for use especially in small children.

Although the tests used in this study are thought to have many advantages and assess abilities relative to daily function, the authors are not suggesting that the tests are more accurate or should be used in place of gold standard clinical tests such as bithermal caloric irrigation. These tests, however, could prove to be useful when testing the younger population or when clinical equipment is not available. It would be beneficial to correlate changes on these balance tests with changes seen in clinical tests of the vestibular system and to determine what amount of change should be deemed significant.

One advantage of this study is that all the subjects included were implanted at the same medical facility by one of 5 surgeons; all of whom conduct the same anteriorinferior cochleostomy placement and atraumatic insertion procedure. Surgeons have become more attentive to performing atraumatic insertions in an effort to preserve residual hearing and have found this anteriorinferior approach to be successful. It is plausible that different approaches in surgical procedures could impact the effects to the vestibular system. Todt et al. examined if two different cochleostomy techniques had an impact on the patient's report of dizziness following surgery (Todt et al. 2008). 62 patients were evaluated, to determine if significant differences were seen between the patients who underwent surgery using the round window approach versus those which an anteroposterior approach was used. Normal vestibular-evoked myogenic potentials (VEMP) responses were seen in 50% of patients who underwent the round window approach versus 13% who underwent the anteroposteriaor approach. Likewise, normal electromystagmography (ENG) results were seen in 43% versus 9% of patients, respectively. The number of patients who reported symptoms of dizziness following surgery as shown by the DHI was found to be 23% for the round window approach versus 13% for the antereoposterior approach. Although this study suggests the use of the round window approach to avoid vestibular effects, the results of this present study shows few significant effects to balance using this more advanced antereoposterior favored by many surgeons. Since the antereoposterior approach is thought to be successful in preserving residual hearing, further research is also needed to determine if these techniques will also help to preserve vestibular function.

Limitations

While this study incorporated novel and functional ways to assess change in patients' balance, there are a number of study limitations that need to be acknowledged. First, this study was limited by the number of patients undergoing cochlear implantation at Washington University Medical Center and St. Louis Children's Hospital during the 9 months of the study. Therefore, our original sample size estimate of 64 implant recipients was not achievable.

Second, the tests used in this study are not standard tests of vestibular function but are clinical assessments used mainly by physical therapists and were developed to assess balance function and the risk for falling. These testing paradigms would serve to quickly and easily assess balance function in children and adults, however, further research is needed to determine their validity and reliability. Further research is also needed to determine if the results of these paradigms correlate with change in vestibular function based on standard clinical tests and the amount of change that is considered significant for each of these tests of balance function.

CONCLUSIONS

The dynamic and static balance tests used in this study were found to be simple and easy to evaluate balance function of both children and adults. The tandem Romberg with EC and the parallel stance on foam EC showed significant change in overall group data following cochlear implantation. Individual data showed significant decreases in 36% of subjects in at least one test of balance, however, no losses were found to be debilitating to daily function. No significant association was found between changes observed and the type of procedure (unilateral or bilateral). Likewise there was no significant association found between subject age and the change observed from pre-to post-implantation. These findings warrant further study but should be considered when counseling patients on the risks of balance dysfunction following cochlear implantation.

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APPENDIX A

Berg Balance Scale

Scoring: A five-point ordinal scale, ranging from 0-4. “0” indicates the lowest level of function and “4” the highest level of function.

Total Score = 56

Interpretation:
41-56 = low fall risk
21-40 = medium fall risk
0 –20 = high fall risk

1. SITTING TO STANDING

Please stand up. Try not to use your hand for support.

( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or stabilize
( ) 0 needs moderate or maximal assist to stand

2. STANDING UNSUPPORTED

Please stand for two minutes without holding on.

( ) 4 able to stand safely for 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unsupported

3. STANDING UNSUPPORTED WITH EYES CLOSED

Please close your eyes and stand still for 10 seconds.

( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays safely
( ) 0 needs help to keep from falling

4. STANDING UNSUPPORTED WITH FEET TOGETHER

Place your feet together and stand while clasping your hands

( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand 1 minute with supervision
( ) 2 able to place feet together independently but unable to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds

5. STANDING TO SITTING

Please sit down.

( ) 4 sits safely with minimal use of hands
( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assist to sit

NOTE: If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

6. SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL

Please sit with arms folded for 2 minutes.

( ) 4 able to sit safely and securely for 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to able to sit 30 seconds
( ) 1 able to sit 10 seconds
( ) 0 unable to sit without support 10 seconds

7. TRANSFERS

Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests.

( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cuing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

8. REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING

<u>Stretch out your fingers and reach forward as far as you can.
Use both arms when reaching & Avoid rotation of the trunk</u>

( ) 4 can reach forward confidently 25 cm (10 inches)
( ) 3 can reach forward 12 cm (5 inches)
( ) 2 can reach forward 5 cm (2 inches)
( ) 1 reaches forward but needs supervision
( ) 0 loses balance while trying/requires external support

9. PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION

<u>Pick up the shoe/slipper, which is place in front of your feet.</u>

( ) 4 able to pick up slipper safely and easily
( ) 3 able to pick up slipper but needs supervision
( ) 2 unable to pick up but reaches 2-5 cm(1-2 inches) from slipper and keeps balance independently
( ) 1 unable to pick up and needs supervision while trying
( ) 0 unable to try/needs assist to keep from losing balance or falling

10. TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING

<u>Turn to look directly behind you over toward the left shoulder. Repeat to the right.</u>

Examiner may pick an object to look at directly behind the subject

( ) 4 looks behind from both sides and weight shifts well
( ) 3 looks behind one side only other side shows less weight shift
( ) 2 turns sideways only but maintains balance
( ) 1 needs supervision when turning
( ) 0 needs assist to keep from losing balance or falling

11. TURN 360 DEGREES
<u>Turn completely around in a full circle. Then turn a full circle in the other direction.</u>

( ) 4 able to turn 360 degrees safely in 4 seconds or less
( ) 3 able to turn 360 degrees safely one side only 4 seconds or less
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision or verbal cuing
( ) 0 needs assistance while turning

12. PLACE ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED

Place each foot alternately on the step/stool.
Continue until each foot has touch the step/stool four times.

( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps in > 20 seconds
( ) 2 able to complete 4 steps without aid with supervision
( ) 1 able to complete > 2 steps needs minimal assist
( ) 0 needs assistance to keep from falling/unable to try

13. STANDING UNSUPPORTED ONE FOOT IN FRONT

Place one foot directly in front of the other.

( ) 4 able to place foot tandem independently and hold 30 seconds
( ) 3 able to place foot ahead independently and hold 30 seconds
( ) 2 able to take small step independently and hold 30 seconds
( ) 1 needs help to step but can hold 15 seconds
( ) 0 loses balance while stepping or standing

14. STANDING ON ONE LEG

Stand on one leg as long as you can without holding on.

( ) 4 able to lift leg independently and hold > 10 seconds
( ) 3 able to lift leg independently and hold 5-10 seconds
( ) 2 able to lift leg independently and hold ≥ 3 seconds
( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently.
( ) 0 unable to try of needs assist to prevent fall

APPENDIX B

Dynamic Gait Index

Gait level surface _____
Instructions: Walk at your normal speed from here to the next mark (20')
Grading: Mark the lowest category that applies.
(3) Normal: Walks 20', no assistive devices, good sped, no evidence for imbalance, normal gait pattern
(2) Mild Impairment: Walks 20', uses assistive devices, slower speed, mild gait deviations.
(1) Moderate Impairment: Walks 20', slow speed, abnormal gait pattern, evidence for imbalance.
(0) Severe Impairment: Cannot walk 20' without assistance, severe gait deviations or imbalance.

Change in gait speed _____
Instructions: Begin walking at your normal pace (for 5'), when I tell you "go," walk as fast as you can (for 5'). When I tell you "slow," walk as slowly as you can (for 5').
Grading: Mark the lowest category that applies.
(3) Normal: Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast and slow speeds.
(2) Mild Impairment: Is able to change speed but demonstrates mild gait deviations, or not gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.
(1) Moderate Impairment: Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations, or changes speed but has significant gait deviations, or changes speed but loses balance but is able to recover and continue walking.
(0) Severe Impairment: Cannot change speeds, or loses balance and has to reach for wall or be caught.

Gait with horizontal head turns _____
Instructions: Begin walking at your normal pace. When I tell you to "look right," keep walking straight, but turn your head to the right. Keep looking to the right until I tell you, "look left," then keep walking straight and turn your head to the left. Keep your head to the left until I tell you "look straight," then keep walking straight, but return your head to the center.
Grading: Mark the lowest category that applies.
(3) Normal: Performs head turns smoothly with no change in gait.
(2) Mild Impairment: Performs head turns smoothly with slight change in gait velocity, i.e., minor disruption to smooth gait path or uses walking aid.
(1) Moderate Impairment: Performs head turns with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.
(0) Severe Impairment: Performs task with severe disruption of gait, i.e., staggers outside 15" path, loses balance, stops, reaches for wall.

Gait with vertical head turns _____
Instructions: Begin walking at your normal pace. When I tell you to "look up," keep walking straight, but tip your head up. Keep looking up until I tell you, "look down," then keep walking straight and tip your head down. Keep your head down until I tell you "look straight," then keep walking straight, but return your head to the center.
Grading: Mark the lowest category that applies.
(3) Normal: Performs head turns smoothly with no change in gait.
(2) Mild Impairment: Performs head turns smoothly with slight change in gait velocity, i.e., minor disruption to smooth gait path or uses walking aid.
(1) Moderate Impairment: Performs head turns with moderate change in gait velocity, slows down, staggers but recovers, can continue to walk.
(0) Severe Impairment: Performs task with severe disruption of gait, i.e., staggers outside 15" path, loses balance, stops, reaches for wall.

Dynamic Gait Index continued….

Gait and pivot turn _____
Instructions: Begin walking at your normal pace. When I tell you, “turn and stop,” turn as quickly as you can to face the opposite direction and stop.
Grading: Mark the lowest category that applies.
(3) Normal: Pivot turns safely within 3 seconds and stops quickly with no loss of balance.
(2) Mild Impairment: Pivot turns safely in > 3 seconds and stops with no loss of balance.
(1) Moderate Impairment: Turns slowly, requires verbal cueing, requires several small steps to catch balance following turn and stop.
(0) Severe Impairment: Cannot turn safely, requires assistance to turn and stop.

Step over obstacle ____
Instructions: Begin walking at your normal speed. When you come to the shoebox, step over it, not around it, and keep walking.
Grading: Mark the lowest category that applies.
(3) Normal: Is able to step over the box without changing gait speed, no evidence of imbalance.
(2) Mild Impairment: Is able to step over box, but must slow down and adjust steps to clear box safely.
(1) Moderate Impairment: Is able to step over box but must stop, then step over. May require verbal cueing.
(0) Severe Impairment: Cannot perform without assistance.

Step around obstacles _____
Instructions: Begin walking at normal speed. When you come to the first cone (about 6’ away), walk around the right side of it. When you come to the second cone (6’ past first cone), walk around it to the left.
Grading: Mark the lowest category that applies.
(3) Normal: Is able to walk around cones safely without changing gait speed; no evidence of imbalance.
(2) Mild Impairment: Is able to step around both cones, but must slow down and adjust steps to clear cones.
(1) Moderate Impairment: Is able to clear cones but must significantly slow, speed to accomplish task, or requires verbal cueing.
(0) Severe Impairment: Unable to clear cones, walks into one or both cones, or requires physical assistance.

Steps _____
Instructions: Walk up these stairs as you would at home, i.e., using the railing if necessary. At the top, turn around and walk down.
Grading: Mark the lowest category that applies.
(3) Normal: Alternating feet, no rail.
(2) Mild Impairment: Alternating feet, must use rail.
(1) Moderate Impairment: Two feet to a stair, must use rail.
(0) Severe Impairment: Cannot do safely.

TOTAL SCORE: ___ / 24

APPENDIX C

Post-operative Cochlear Implant Balance Questionnaire

Have you experienced dizziness since your cochlear implant surgery?

Yes No

If so, when did the dizziness occur?

Within 24 hours after surgery More than 24 hours after surgery

What best describes the dizziness

☐ Imbalance - *Off-balance, tipsy, wobbly, feeling you might fall*

☐ Lightheadedness - *Feeling you might faint, black out, or lose consciousness*

☐ Vertigo - *tilting, spinning, floating, bobbing, swaying, rocking, or false sense of motion*

Did the dizziness cause you to feel nauseated?

Yes No

Did the dizziness cause you to vomit?

Yes No

Did the dizziness cause you to remain bedridden?

Yes No

Did the dizziness seem to be caused by particular movments or body positions?

Yes No

How often did the dizziness occur?

☐ One time

☐ Short episodes: *less than 5 minutes*

☐ Moderate episodes: *5 minutes to 24 hours*

☐ Long episodes: *1 day to 1 week*

☐ Persistent: longer than 1 week

When you experienced dizziness did you notice any change in your hearing?

Yes No